July 23, 1971

Office of Pipeline Safety
400 6th Street S.W.
Washington, D.C. 20590

Gentlemen:

Enclosed is a proposal from the ASME Gas Piping Standards Committee which recommends a revision to Section 192.105(b) on heat treating cold expanded pipe. The purpose of this proposal is to allow the limited heat treatment of localized hard spots. Hard spots occasionally appear in line pipe and are usually caused by an inadvertent quenching of hot place in the mill as a result of some water dripping on the plate. There have been occasions where these localized hard spots have caused leaks which have been difficult to locate and occasionally have caused failures.

This proposal is based upon work done by the AGA Research Project, "Line Pipe Research," conducted by Battelle. The results of this work are contained in a report: "The Effect of Tempering on the Mechanical Properties of Cold-Expanded Line Pipe," - December 21, 1972. We can provide copies of this report if you wish.

Thank you very much.

M.R. Green
Director, Codes and Standards

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ASME PROPOSAL FOR DOT RULEMAKING
TITLE 49 CFR, PART 192, SECTION 192.105(B)

ASME is proposing a revision to Section 192.105(b) wherein there is a limitation on heating cold expanded pipe above 600°F

without reducing the design pressure to 75 percent of the pressure determined by the design formula in Section 192.105(a).

Some pipelines have localized hard spots in them which have caused failures when the hard spot was attacked by atomic hydrogen causing hydrogen-stress-cracking.

In 1969 and 1970 research work was conducted to determine if these localized hard spots could be tempered without deleterious effects to the pipeline and the research established the fact that cold expanded pipe could be heated to 825°F for one hour without any adverse effects to the pipeline, therefore, ASME is proposing that cold expanded pipe be allowed to be heated to 825°F for one hour without reducing to design pressure as presently set out in Section 192.105(b).

Adoption of the ASME proposal would not be inconsistent with pipeline safety because heating the pipe to 825°F for one hour would have no deleterious effect on the pipe and the potential causes of failure of pipe with hard spots would be eliminated as it takes high hardness, atomic hydrogen, and high stress for hydrogen-stress-cracking to occur and the elimination of the hard spot would remove one of the factors required in the hydrogen-stress-cracking phenomenon.

ASME, therefore, recommends that Section 192.105 Subparagraph (b) be revised to read as follows:

192.105(b) "If steel pipe that has been cold worked to meet the SMYS is heated, other than by welding to more than 600°F, the design pressure is limited to 75 percent of the pressure determined under Paragraph (a) of this section, <u>except that such pipe may be heated to temperatures between 600°F and 825°F for a period not to exceed one (1) hour.</u>

*NOTE: The underlined portion of the proposed 192.105 (b) is the portion added to the Subparagraph (b).

This proposal is based upon the AGA Pipeline Research Committee report by Battelle: "The Effect of Tempering on the Mechanical Properties of Cold-Expanded Line Pipe," 12/21/70.

RESEARCH REPORT

on

NG-18 RESEARCH
THE EFFECT OF TEMPERING ON THE MECHANICAL PROPERTIES OF COLD-EXPANDED LINE-PIPE STEELS

to

AMERICAN GAS ASSOCIATION
PIPELINE RESEARCH COMMITTEE

December 12, 1970
(Revised)

by

T.P. Groeneveld, K.R. Grube, and A.R. Elsea

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

February 17, 1971

Mr. L.E. Hanna
Vice President, Engineering
Panhandle Eastern Pipeline Company
P.O. Box 1348
Kansas City, Missouri 64141

Dear Mr. Hanna:

As a result of discussions at the meeting of the Transmission and Compressor Station Subcommittee of the ASME Gas Piping Standards Committee in Dallas on February 3-4, we have conducted some additional laboratory experiments to determine the effect of elevated temperatures and time at temperature on the properties of cold expanded line pipe steels. Accordingly, the attached report has been revised to incorporate the new data - specifically, tensile properties after tempering at 850° F (previous work included 800° F and 900° F).

On the basis of the new information, we have revised our recommendations on the maximum temperature at which pipe can be heated without decreasing the design stresses. We suggest that a maximum temperature of 825° F be allowed (aimed at Paragraph 192.105 of the DOT requirements).

Several other aspects on this subject were also discussed in the Dallas meeting and, since the meeting, we have considered and discussed these with appropriate staff members. Our comments on two of these areas are as follows:

> <u>The Possibility of Blue Brittleness Effects.</u> According to the ASM Metals Handbook, "Blue brittleness" is defined as, "Brittleness exhibited by some steels after being heated to some temperature within the range of 300° to 650° F and

more especially if the steel is worked at the elevated temperature. Killed steels are virtually free of this kind of brittleness."

Upon heating to or cooling from the proposed tempering temperature, time in the critical temperature range (300° to 650° F) will be too short for adverse reactions to occur. (These reactions are generally conceded to be precipitation reactions and require time at temperature.) If these adverse or precipitation reactions had occurred while the material was in the critical temperature range or at any time during the tempering treatment then it would be expected that the occurrence would be reflected in the properties measured afterward at room temperature. The measured tensile and notch-impact room-temperature properties as shown in the attached report indicate that no significant effect was observed.

Time at Temperature. This is an important variable and additional experimental data have been obtained. Evaluation of six lots of X-52 steel showed that these steels could be tempered for 1 hour at 825° F without reducing their yield strengths from the untempered values. Evaluation of three lots of X-60 steel and three lots of X-65 steel showed that these steels could be tempered for 1 hour at 925° F without reducing their yield strengths from the untempered values. Data obtained from the X-52 steels tempered at 850° F for 1 and 3 hours, respectively, showed that increasing the time and temperature generally lowered the yield strengths, as would be expected. Therefore, the time of the tempering treatments should be limited to 1 hour.

If after reviewing this modification, you have any questions or comments, we will be happy to discuss them with you.

Sincerely,

George McClure

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NG-18 RESEARCH

THE EFFECT OF TEMPERING ON THE MECHANICAL PROPERTIES OF COLD-EXPANDED LINE-PIPE STEELS

by

T.P. Groeneveld, K.R. Grube, and A.R. Elsea

INTRODUCTION

Since the mid-1950's, a number of failures and leaks in cathodically protected line pipe have initiated in localized hard spots in the pipe wall. These spots had hardnesses in excess of 360 Brinell (equivalent to an ultimate tensile strength of about 175 ksi). They were formed by inadvertent quenching of localized areas of the pipe skelp [sic] on the runout table immediately after the final hot-rolling pass in the steel mill. Analysis of these failures indicated that cracks ultimately resulting in the ruptures or leaks, had initiated by hydrogen stress cracking (HSC).

HSC is a time-dependent failure mechanism that can occur in high-strength steels that are subjected to a sustained tensile stress below their yield strength when atomic hydrogen is present in the steel. If the appropriate conditions are satisfied, the steel can fail in a brittle manner after a period of time. The mode of failure is also termed hydrogen-induced delayed brittle failure.

As a result of considerable research on the HSC phenomenon, it has been shown that, as the strength or hardness of a steel increases above some minimum value, the steel is susceptible to failure by HSC. As the strength or hardness is increased further, the applied stress required to cause failure, the necessary hydrogen content, and the time for failure to occur all decrease. In a hard spot in an operating gas-transmission pipeline, at least two of the conditions for HSC are satisfied: (1) the steel in this region has high hardness (the hardness of the majority of the hard spots examined was over 400 Brinell) and (2) this region is subjected to a sustained tensile stress in the circumferential (hoop) direction from the internal gas pressure. All that is required to initiate HSC is for sufficient atomic hydrogen to be present in the steel. Atomic hydrogen can be deposited on the surface of the hard-spot region as a result of the cathodic-protection reactions, and part of this atomic hydrogen can be absorbed by the steel.

In 1968, a device that could locate, nondestructively, hard spots in operating pipelines became available. A short time later the scope of the Hydrogen-Stress-Cracking Phase of the program at Battelle was expanded to include studies of the factors that cause some hard spots to fail while others do not, and the evaluation of methods that could be employed to minimize or prevent the initiation of failures in hard spots once they have been found by the nondestructive testing device.

One method that could be used to minimize such failures consists of locally tempering the hard spot so as to reduce the hardness (and strength) to a level at which HSC would be unlikely to occur. Laboratory studies and field studies have been cond- **(Note: the last line of the letter could not be read!)**
to HSC in solid environment. The results indicated that steels with yield strengths below 150 ksi (ultimate tensile strengths below about 170 ksi or hardness below about 350 Brinell) do not fail at applied stresses of the magnitude encountered in normal operations when pipelines in soils are cathodically protected. This strength level (hardness) also is below that of the hard spot of lowest hardness that has failed in service. Therefore, this strength level was selected as the maximum desired after tempering. Because of the direct relationship between strength level and susceptibility to HSC, lower strength levels than this would be more desirable.

Data were reviewed for various lots of X-52 steels that were heat treated to provide specimens of various strength levels for the laboratory and field studies. These data indicated that, to achieve a hardness of about 350 Brinell after tempering, the hard spots should be tempered at 800°F; increasing the tempering temperature to 1000°F would drop the hardness to about 290 Brinell or below. However, the DOT Gas Pipeline Safety Standards places a limit of 600°F on the temperature to which a cold-expanded pipe can be heated without subsequently lowering the maximum allowable operating pressure to 75 percent of the value calculated from the design-stress formula. This limitation for heating of cold-expanded pipe was taken from the ANSI B31.8 Code. This limitation has been in the Code since the original edition was issued in the mid-1950's. At that time, the temperature of 600°F was selected by committee discussion and judgment; the decision was not based on performance or operating data. The original thought was that, if the pipe were heated above 600°F, the increase in yield strength of the steel caused by cold work (cold expansion) during the manufacture of the pipe would be lost because of stress relief. However, stress relief that may occur when a cold-worked steel is heated will not necessarily reduce the yield strength of the steel.

Because of the current DOT limitation, tempering of hard spots to reduce their susceptibility to HSC would not be a suitable remedial treatment for the gas-transmission companies for economic reasons. The maximum allowable gas pressure would have to be reduced and, thus, the gas throughout would be reduced. A preliminary study was conducted to determine the effect of tempering (at about 1000°F) on the mechanical properties of cold-expanded pipe steel; a hard spot in the pipe was tempered using an exothermic device. The data obtained were encouraging; consequently, the program was expanded to obtain data to support a code change that would allow tempering of hard spots at temperatures above 600°F without having to reduce the maximum allowable gas pressure after the tempering treatment was completed. In addition, the elevated-temperature strength of the pipe steel was measured at temperatures corresponding to the selected tempering temperatures to determine the level of internal gas pressure that could be supported by the pipe during the tempering treatments. This report describes these studies.

SUMMARY

During 1969, preliminary studies were conducted to determine (1) the feasibility of using localized tempering treatments to soften hard spots in line pipe to a level at which they would be insensitive to HSC under normal gas-transmission-pipeline operating conditions and (2) the influence of such treatments on the mechanical properties of the cold-expanded pipe steel. These studies indicated that tempering for 30 minutes at temperatures up to 1000°F did not reduce the yield strength of the X-52 base steel below those of untempered pipe. A hard spot that had been removed from an operating pipeline was tempered, using an exothermic device designed to heat the pipe to 1000°F. The tempering treatment reduced the hardness of the steel in the hard spot to a satisfactory level. However, the maximum temperature of the steel exceeded (by 75°F) the anticipated maximum of 1000°F, and the yield strength of the adjacent base metal was reduced by about 5.5 percent from its value in the untempered condition. Thus, another method for heating pipe by which the temperature could be controlled more readily, such as the use of an electrical-resistance-heated device, would be more desirable to use for tempering.

On the basis of the encouraging results of the preliminary studies, a more extensive evaluation of the influence of tempering treatments at temperatures up to 1000°F on the mechanical properties of several cold-expanded line-pipe steels, representing X-52, X-60, and X-65 grades, was undertaken in 1970. These studies were conducted to provide data to support a code change that would allow heating the pipe to temperatures above 600°F without having to reduce the maximum allowable operating pressure to 75 percent of the value derived from the designed-stress formula. Evaluation of six lots of X-52 steel showed that the steel could be tempered at 825°F for one hour without reducing its yield strength from the untempered values. Evaluation of three lots of X-60 steel and three lots of X-65 steel indicated that the yield strengths of these grades were not reduced after tempering for 1 hour at temperatures up to about 925°F.

To provide an indication of the level of internal gas pressure that could be supported by the pipe during a tempering treatment, the tensile properties of three lots of X-52 steel were determined at 800°F, and the properties of one lot of X-60 and one lot of X-65 steel were determined at 800° and 900°F. The yield strengths at temperature, expressed as a percent of room-temperature yield strength, are shown below:

DIAGRAM:

EXPERIMENTAL PROGRAM

Preliminary Tempering Studies - 1969

Experimental Procedures

The preliminary tempering studies were conducted during 1969 using two joints of ?30 x 0.375-inch, X-52, cold-expanded line pipe that contained hard spots; these joints had been removed from an operating pipeline. Initially, flat, strap tensile specimens, as shown in Figure 1, and Battelle drop-weight tear-test (BDWTT) specimens, as shown in Figure 2, were machined from a section of one of the joints of pipe, designated as UGJ-4. The tensile specimens were removed from the pipe in both the longitudinal and transverse directions (parallel with and perpendicular to the rolling direction, respectively), while the BDWTT specimens were in the transverse direction only. All the specimens in the transverse direction were machined from a section of the pipe that had been flattened by reverse bending. However, the longitudinal tensile specimens were machined from a section that was not flattened; thus, no additional cold work, that could change the tensile properties, was introduced into these specimens.

FIGURE 1: FLAT, STRAP TENSILE SPECIMEN USED TO DETERMINE THE TENSILE PROPERTIES OF THE STEELS

FIGURE 2: DROP-WEIGHT TEAR-TEST SPECIMENS AND SUPPORT DIMENSIONS AND TOLERANCES FOR SPECIMENS 1/8 TO 3/4 INCH IN THICKNESS

The tensile specimens were tempered for 30 minutes at temperature representing 100°F intervals between 600°F and 1000°F; the BDWTT specimens were tempered for 30 minutes at 800°F or 1000°F. The tensile properties were measured using a universal tensile testing machine. The specimens were pulled at a platen head speed of 0.02 ipm [inches per minute] until yielding occurred; the head speed then was increased to 0.2 ipm and this speed was used until failure occurred. Load-deformation curves were obtained for each specimen using a recording extensometer attached to the reduced section. For comparison purposes, the tensile and impact properties also were determined using specimens that had not been tempered.

Subsequently, a region containing the hard spot in the other joint of pipe, designated as UGJ-5, was tempered using an exothermic device designed for the 800°F to 1000°F temperature range. The device covered a circumferential section of the pipe that was 2 feet long. The location of the device with respect to the hard spot and the locations of 12 thermocouples used to measure the temperature at various locations in the tempered region are shown in Figure 3. During the tempering treatment, the temperature in the region was above 800°F for 75 minutes and above 1000°F for about 25 minutes; the maximum temperature recorded in the region from which the specimens were removed was 1075°F. After the tempering treatment, the pipe was sectioned and then was flattened by reverse bending. Strap tensile specimens and BDWTT specimens were machined from the tempered base metal adjacent to the hard spot. Specimens from a region of the pipe that had not been tempered also were prepared to provide data for comparison purposes. All of the specimens from this joint of pipe were taken in the transverse direction, and the mechanical properties were determined using the procedures described previously. In addition, the hardness of the steel was determined at selected regions within the tempered hard spot, using a portable Brinell hardness tester, to compare with the hardness prior to tempering and thus determine the effectiveness of the tempering treatment.

Results and Discussion

The mechanical properties of the specimens from Pipe UGJ-4 in the as-received condition (untempered) and after tempering for 30 minutes at temperatures in the range from 600°F to 1000 °F are listed in Table 1. For both the longitudinal and transverse specimens, the yield strength generally increased with tempering temperature up to 800°F and then decreased as the temperature was increased further to 1000°F. However, even after tempering at 1000°F, the yield strength was equal to or higher than that of the untempered specimens. Furthermore, the 80 percent shear-area transition temperature (BDWTT) was lowered by 10° and 32°F by tempering at 800° and 1000°F, respectively. This lowering of the shear-area transition temperature (SATT) was accompanied by a loss in shelf energy absorption of 165 ft-lb and 75 ft-lb, respectively.

Examination of the microstructure of the specimens after tempering revealed that no microstructural changes had occurred. Typical microstructure of the untempered steel and the steel after tempering for 30 minutes at 1000°F are illustrated in Figure 4.

The mechanical properties of the specimens from Pipe UGJ-5, both untempered and as tempered with the exothermic device, also are listed in Table 1. These data show that the yield strength of the steel was reduced by 3,100 psi, or about 5.5 percent, by

FIGURE 3: DIAGRAM OF THE POSITION OF THE EXOTHERMIC DEVICE, THERMOCOUPLES, AND THE LIGHTING HOLES ON THE SURFACE OF THE PIPE, OVER THE HARD SPOT

FIGURE 4: TYPICAL MICROSTRUCTURES OF STEEL UGJ-4 BEFORE AND AFTER TEMPERING AT 1000°F FOR 30 MINUTES

TABLE 1: EFFECT OF TEMPERING ON THE MECHANICAL PROPERTIES OF COLD-EXPANDED X-52 LINE PIPE REMOVED FROM AN OPERATING PIPELINE[(a)(b)]

the tempering treatment, while the 80 percent SATT was essentially unchanged. The fact that the yield strength after tempering was lower than that of the untempered steel was attributed to the higher-than-expected temperature generated by the exothermic device (1075°F versus 1000°F).

Brinell hardnesses at selected locations within the hard-spot region, showed that the hardness was reduced to a satisfactory level by the tempering treatment performed with the exothermic device. The maximum hardness measured prior to tempering was 440 Brinell; after tempering, the maximum hardness was 280 Brinell and the majority of the hardness readings were below 250 Brinell.

The preliminary tempering studies indicated that localized tempering of hard spots was feasible and that treatments of 30 minutes at temperatures up to 1000°F did not reduce the yield strength of the steel to below that of the untempered material. As the device used in this study exceeded its design maximum temperature by 75°F, some more-readily-controlled method of locally heating the pipe may be more desirable than an exothermic device. However, by using an electric-resistance-heated pad to which the current can be controlled, in conjunction with a thermocouple, the temperature should be more readily controllable, and problems of overheating should be minimized.

As the results of the preliminary studies were encouraging, additional tempering studies were conducted during 1970 to obtain data to support a code change that would allow tempering of hard spots at temperatures above 600°F without subsequently having to reduce the maximum allowable operating pressure.

Tempering Studies - 1970

Experimental Procedures

Twelve lots of cold-expanded line-pipe steel were selected from the AGA inventory at Battelle-Columbus for more extensive tempering studies. Of these lots of steel, six were X-52, three were X-60, and three were X-65 grade. The dimensions and chemical compositions of the 12 lots of pipe used are listed in Table 2.

TABLE 2: DIMENSIONS OF THE PIPES AND CHEMICAL COMPOSITIONS OF THE STEELS SELECTED FOR THE TEMPERING STUDIES

A ring section approximately 3 feet long was cut from each of the 12 lots of pipe. These ring sections subsequently were cut longitudinally into three sections approximately 2.5 feet wide by 3 feet long. After grinding the torch-cut edges, each section was flattened by reverse rolling. The flattened plates then were sawed into two sections (one 23 inches long and the other 13 inches long) to facilitate handling in the subsequent heat treatment and to provide material for evaluation of the mechanical properties in the untempered condition.

The three 23 by 30-inch plates from each lot of steel were tempered in a circulating air electric furnace at temperatures of 800°, 900°, and 1000°F. Six plates were tempered at a given temperature at one time. They were supported on edge in an angle-iron frame and were spaced 2 inches apart so as to provide adequate air circulation around each plate and uniform heating during the tempering treatment. A glass-insulated Chromel-Alumel thermocouple was peened into one of the center plates of each group of six and was attached to a recorder. The plates were held at temperature for 1 hour after the thermocouple indicated that the center plate had reached the desired temperature. After tempering, the plates were removed from the furnace and allowed to air cool to room temperature.

From each of the tempered plates, 2 strap tensile and 12 BDWTT specimens (shown in Figures 1 and 2, respectively) were machined. All specimens had the transverse orientation, that is, the major axis was perpendicular to the rolling direction of the plate. The specimens were taken sufficiently far away from any of the "burned" edges so as not to be affected by the high-temperature localized heating from the torch-cutting operation. Prior to tensile testing, it was necessary to flatten the individual specimens by reverse bending with three-point loading to assure axial alignment of grips and specimen. The surfaces were wire brushed to remove andy loose scale. All tensile testing was done on a universal testing machine using a platen head speed of 0.02 ipm. Deformation was measured at frequent intervals using a 2-inch-gage-length averaging extensometer clamped to the machined edges of the reduced section. Load-deformation curves were plotted, and the yield strength at 0.5 percent total strain was calculated.

Rockwell B hardness measurements were taken on tempered material on sections cut and polished from those portions of the grip ends of the tensile specimens farthest removed from the reduced section. The measurements were taken on the cut face at right angles to the pipe surface. This area was the one least likely to be deformed plastically, and, hence, work hardened, by the tensile test.

As discussed in a subsequent section, the tensile properties of the X-52 steels tempered for 1 hour indicated that the maximum temperature to which these steels could be heated without reducing their yield strengths below those in the untempered condition was between 800° and 900 °F. Since 800°F is the minimum tempering temperature, from the standpoint of softening hard spots, that should be used, additional experiments were performed to determine the maximum temperature that could be used for X-52 pipe steels without reducing their yield strengths below their untempered values. Also some experiments were performed to determine the effect of time of tempering on the tensile properties of the X-52 steels. The tempering treatments were as follows: 850°F for 1 hour, 850°F for 3 hours, and 900°F for 0.5 hour. Because of a shortage of material, Steel W-8 was not tempered at 850°F for 3 hours. Following these treatments, the tensile properties of the steels were determined on strap tensile specimens (transverse orientation) by the procedures described previously.

On the basis of the room-temperature tensile tests, three steels (GG-1, A4-2, EE-4) were selected from the X-52 group, one (TT-1) from the X-60 group, and one (BF-7) from the X-65 group for tensile testing at elevated temperatures. The specimens were taken from untempered plate in the transverse orientation and were machined according to the design shown in Figure 5. The X-52 material was tested at 800°F; the X-60 and X-65 steels, at 800° and 900°F. Again, no preparation was made of the surface in the reduced section other than wire brushing.

FIGURE 5: DETAILS OF THE FLAT, STRAP, TENSILE SPECIMEN USED TO DETERMINE THE ELEVATED-TEMPERATURE TENSILE PROPERTIES OF SELECTED LOTS OF PIPE STEEL

Two Chromel-Alumel thermocouple were attached to the gage length of the specimen. The specimens were fitted to special pin-type grips and then were placed in a furnace that was attached to the tensile machine and had been preheated to the desired temperature. When the two thermocouple indicated that a temperature within ±5°F of the desired test temperature had been reached, the time was noted and then the specimens were held for 1 hour at temperature prior to testing. The specimens were pulled at a head speed of 0.005 ipm until yielding occurred; the head speed then was increased to 0.05 ipm until failure occurred. Because of space limitations within the furnace, an extensometer could not be used to obtain the load-deformation curves. Therefore, these curves were obtained by using a recording compressometer between the bottom platen and the table of the tensile machine. The yield strengths of the specimens were calculated from the load obtained at 0.2-percent-offset on the curves.

Results and Discussion

The mechanical properties of the 12 lots of steel in the untempered condition and after tempering for 1 hour at the indicated temperatures are summarized in Table 3. In as much as the yield strength of the steel is the only property used in the design-stress formula, the suitability of the tempering treatments was assessed primarily on the basis of their influence on the yield strength of the steel. The yield strengths of the steels as a function of tempering for 1 hour at temperatures from 800°F to 1000°F are shown in Figure 6. For 10 of the 12 lots of steel, the yield strength was higher after tempering for 1 hour at 800°F than for any other condition evaluated. (For the other steels, EE-4 and TT-1, the yield strengths were highest after tempering at 850° and 900°F, respectively.) The yield strength then decreased with further increase in tempering temperature such that after tempering at 850°F the yield strengths of two of the X-52 steels, A-4-2 and X-4, were lower than their untempered values by 800 and 200 psi, respectively. The yield strengths of all the X-60 steels were lower than their untempered values after tempering at 1000°F, and the yield strength of one of the X-65 steels, AB-3 was lower than its untempered value after tempering at 1000° F. The ultimate tensile strength of the steels

FIGURE 6: THE EFFECT OF TEMPERING FOR 1 HOUR AT TEMPERATURES FROM 800°F TO 1000°F ON THE YIELD STRENGTH OF X-52, X-60, AND X-65 PIPE STEELS

TABLE 3: THE EFFECT OF TEMPERING FOR 1 HOUR AT TEMPERATURES FROM 800°F TO 1000°F ON THE MECHANICAL PROPERTIES OF COLD- EXPANDED X-52, X-60, AND X-65 PIPELINE STEEL[a]

generally showed the same trend as a function of tempering temperature as did the yield strength; however, the ultimate tensile strengths for two of the steels were reduced from their untempered values by all of the tempering treatments. The hardness of the steels after tempering generally reflected the changes in strength. As expected, the ductility of the steels showed the opposite trend as a function of tempering temperature; that is, it generally was lower after tempering at 800 °F and then increased with increasing tempering temperature. However, in none of the steels was the ductility drastically reduced by the tempering treatments. Furthermore, tempering generally improved the fracture toughness of the steels, as indicated by the lowering of the 80 percent SATT determined with the BDWTT. For those steels that showed an increase in the 80 percent SATT after certain tempering treatments, the increase was generally only about 5° to 10°F. For one case the SATT was raised 25°F (from 0°F to +25°F). The ductile-fracture-shelf energy absorption was changed somewhat as a result of the tempering treatments. However, there was no consistent trend in the change in energy absorption as a function of tempering temperature.

The data from the studies to determine the effect of tempering time on the tensile properties of the X-52 steels are summarized in Table 4. For purposes of comparison, the tensile properties of the steels in the untempered condition are included. The data show that increasing the tempering time to 3 hours at 850°F reduced the yield strengths of 3 of the 5 steels evaluated to values below those obtained by tempering 1 hour at 800°F; 2 were reduced to values below those in the untempered conditions.

Experience and general state of the art for the tempering of steels would indicate that tempering at 900°F for 0.5 hour would soften hard spots as much as or more than would tempering them at 800°F for 1 hour. However, tempering at 900°F for 0.5 hour reduced the yield strengths of three of the X-52 steels to values below those in the untempered condition.

To determine the maximum temperature at which the various grades of pipe steel could be tempered, the following criterion was used: the yield strength of the pipe after tempering could not be lower than the yield strength of the untempered steel. This criterion was selected on the assumption that the yield strength of some of the joints of pipe in a given pipeline could be the specified minimum value for the particular grade. Since the maximum allowable operating pressure for the line is calculated using the specified minimum yield strength (SMYS), any treatment that reduces the yield strength of a pipe steel would reduce the yield strength of some of the joints of pipe to below the SMYS.

Using this criterion, the data indicate that cold-expanded X-52 steels can be heated to temperatures of about 825°F, as is shown in Figure 6, and that the time at temperature should not exceed 1 hour. The X-60 and X-65 steels can be heated to temperatures up to about 925°F for 1 hour, as is shown in Figure 6.

Another portion of this study concerned a determination of the level of internal gas pressure that could be supported by the pipe during a tempering treatment. This information was needed to determine whether the line must be removed from service during such treatments. In the measurement of the strength of the steel at the tempering temperature, elevated-temperature tensile tests of the three grades of steel were conducted at 800°F for the X-52 steels and 800° and 900°F for the X-60 and X-65.

TABLE 4: EFFECT OF TIME DURING TEMPERING AT 850°F AND 900°F ON THE TENSILE PROPERTIES[a] OF COLD EXPANDED X-52 LINE PIPE STEELS

TABLE 5: THE EFFECT OF TEST TEMPERATURE ON THE TENSILE PROPERTIES OF THREE GRADES OF PIPELINE STEEL

These data show that the yield strengths (0.2 percent offset) of three lots of X-52 steel were between 12 and 20 percent lower at 800°F than at room temperature, and that the yield strengths of X-60 and X-65 steels were about 25 percent and 17 percent lower, respectively, at 800°F than their yield strengths at room temperature. At 900°F, the yield strengths of the X-60 and X-65 steels were 36 percent and 28 percent lower, respectively, than those at room temperature. The ultimate tensile strengths of the steels at 800°F were reduced by about the same percentages as the yield strengths. However, at 900°F, the ultimate tensile strengths of the X-60 and X-65 steels were lower by about 40 and 32 percent, respectively. The ductility of the steels was not significantly influenced by the test temperature. One of the X-52 steels, GG-1, showed about an 8 percent reduction in elongation at 800°F, and the X-60 and X-65 steels exhibited increases in elongation of 17 percent and 9 percent, respectively, at 900°F. Thus, the elevated-temperature tensile data have indicated that X-52 steels could support about 80 percent of the maximum allowable operating pressure during a 1 hour tempering treatment at 800°F; the X-60 steel could support 75 percent and 64 percent of the pressure at 800°F and 900°F, respectively; and the X-65 steels could support 83 percent and 72 percent of the pressure at 800°F and 900°F, respectively. However, in actual practice, the pressure probably would be reduced to values somewhat lower than these during a tempering treatment.

The data used to prepare this report are contained in Battelle-Columbus Laboratory Record Books 26590 and 27778.